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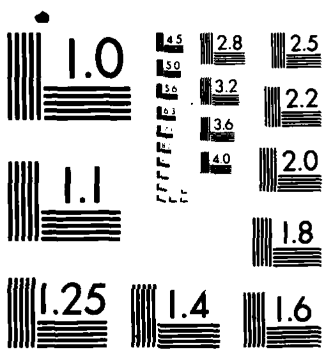

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AD-A161 234

HELICOPTER-REFERENCED SINGLE CONTROL, CENTER-POSITION FORCE EXERTION CAPABILITIES OF MALES AND FEMALES

By

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20. ABSTRACT

In response to the need for reevaluation of anthropometric criteria contained in the US Army medical standards for flying duty, an assessment was made of helicopter-control-referenced force exertion capabilities of a sample of Army males and females. Males (N=74) ranged from 159 cm through 196 cm in stature; females (N=66) ranged from 152 cm through 183 cm. The force-exertion data were compared to values cited in MIL-H-8501A as upper force limits for the design of helicopter controls. The focuses of the analyses were upon the force exertion capabilities of individuals 167 cm (65.7 inches) and below in stature since, by virtue of their relatively small size, they represent the portion of the population which are most apt to evidence inabilities to exert forces which equal or exceed control force design limits. The comparison revealed that, overall, the presently existing limits (published in 1961) for other-than-the normal operational flight envelope exceeded the force exertion capabilities of 10 percent of the 39 small males evaluated and 27 percent of the 56 females evaluated. Most failures to achieve existing or proposed control force design limits occurred because of inabilities to attain criterion-level exertions in the downward direction on the collective. Predicated upon the force exertion data from the small individuals of this study, various combinations of specific control force design limits were evaluated to develop estimations of overall "set-wise" failure rates likely to be encountered during possible future strength testing/screening. Because testing entailed no incentive for participation and involved multiple exertions within the session, it is anticipated that the percentage of failures encountered represent an overestimation of the failure-rate which would likely be encountered in the future while testing the strength capability of short individuals actually seeking to become or remain as aviators.

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INTRODUCTION

OVERVIEW

This report is one of a series of reports pertaining to a reexamination of the anthropometric requirements for Classes 1, 1A, and 2 flying duty for US Army aviators. These criteria appear in Chapter 4, Army Regulation (AR) 40-501, Medical Services Standards of Fitness (Department of the Army 1960). At present, there are no minimum strength criteria in AR 40-501. The US Army Aeromedical Research Laboratory (USAARL) response (USAARL letter to US Army Medical Research and Development Command (USAMRDC), May 1980) which conveyed the results of the initial anthropometric cockpit compatibility evaluation undertaken by the first author also cited the need for concern regarding minimum physical strength criteria. This concern derived from the following: (a) the provisionally-adopted anthropometric criteria permitted smaller males (1st-2d percentile males vs 5th percentile, previously) and more and smaller females (those in the 20-35th percentile and above vs the 50th percentile and above, previously) to enter the program; (b) size is generally positively correlated with strength: and (c) the upper body strength of females is approximately one-half to two-thirds that of males of comparable stature. The principal issue is whether or not smaller personnel who are accepted into the flight program are physically capable of sustaining control of the aircraft during emergency (hydraulic failure) conditions. The research reported here describes the findings of a substantial evaluation of gender- and stature-related factors related to helicopter-control-referenced force exertion capabilities.

PREVIOUS RESEARCH FINDINGS

The general topic of physical strength and endurance has a substantial research literature. McCormick (1976) has indicated that age, sex, body build, and an individual's general physical condition are principal factors in determining strength and endurance. In general, physical size is positively correlated with strength. Data from males (Caldwell 1964; Thorsden, Kroemer, and Laubach 1972) and females (Leeper, Hasbrook, and Purswell 1973) indicate moderately large positive correlations (.3 to .6) between many measures of strength and an individual's weight and stature.

Overall, women are approximately two-thirds as strong as men of comparable size (McCormick 1976). Force outputs also vary markedly according to the particular limb employed. Laubach's (1975) study focused specifically upon the

combination of both factors; i.e., gender-related strength differences among the various limbs. He found that the smallest mean difference was observed among the lower extremities. Females were 72 percent as strong as males of corresponding stature. With the upper extremities, females were 60 percent as strong as males. The study also noted that percentage differences between the sexes were relatively constant at corresponding percentile reference points.

In subsequent reviews of the literature, Laubach (1976, 1978) reported that measurements obtained from the upper extremities showed that women's strength, depending upon the specific exertion involved, ranged between 35-79 percent that of men. The mean percentage difference was 56 percent. Comparisons involving lower extremities showed women to be 72 percent as strong as men; the range was 57-86 percent. Measures of trunk strengths were intermediate (mean = 64 percent, range = 37-78 percent). Dynamic strength comparisons between men and women revealed women's strength to be 69 percent as large as those for men. The range was 59-84 percent.

Anthropometric studies recently completed for the US Army (Churchill et al. 1977; McConville et al. 1977) have included a series of static strength measures which permit a more direct comparison of the populations most relevant to the present research. Unfortunately, most exertions measured were, for the most part, not pertinent to those found in the aviation cockpit environment. Most were two-handed vertical lifts or pushes--akin to the type of movements involved in lifting or moving boxes with handles. However, two measures were obtained which are somewhat related to the present concern; the "seated one-handed pull--centerline of seat," and the "seated one-handed pull--side of seat." For the centerline measure, the initial mean female peak exertions, and the mean 3-second, time-averaged exertions were approximately one-half as large as the corresponding values for males (51 percent and 47 percent, respectively). The side-of-seat exertions would appear to have more relevance since they corresponded roughly to the position assumed when pulling up on the "collective" control of a helicopter, albeit these exertions were performed with the individual's right hand (in contrast to the left-hand exertions required to operate the collective of a helicopter). These data suggest that for this position the average female exertion was approximately 55 percent as great as that of the average male.

The issue of force requirements within an aviation cockpit environment was directly addressed by Thorsden, Kroemer, and Laubach (1972). Studies were made of maximal isometric force exertions at various locations for hand-operated controls positioned relative to a simulated aircraft seat. The information most directly related to the present

research is that pertaining to the exertions made on the "stick" (similar to the cyclic) and "collective" controls. Although the data were obtained only from males, it is informative in that they provide an appreciation of the variation which exists as a result of (a) differences in the direction of the force applied, and (b) the extent of variation among subjects. For instance, the right-handed inputs to the left on the vertically positioned "stick" were 30 percent larger than those applied to the right. Individual differences were such that the value for the 99th percentile exertion was approximately three times that of the first percentile value for both left and right exertions.

A study was conducted by Leeper, Hasbrook, and Purswell (1973) on the issue of aircraft-control-referenced strength capabilities among female pilots. Tests were made of the duration of time for which female pilots could maintain specified levels of force exertions on the three principal controls of fixed-wing aircraft. These data were compared to force control limits included in the guidance provided by Federal Aviation Regulation (FAR) existing at that time. For elevator strength endurance tests, it was found that in contrast to the 75-pound (337.5 N), 20-second standard for temporary elevator control force applications, 58 percent of the 24 women tested could not maintain a 55-pound (247.5 N) pull for 20 seconds. (The regulation-specified 75-pound limit was not tested.) Aileron control performance was considerably worse. The regulation specification and Federal Aviation Administration (FAA) guidance cited a value of 62 pounds (279.0 N) to be maintained for 20 seconds; however, the maximum force tested was 22 pounds (99 N). Even at that level, 17 percent of the females tested could not maintain the force for a period of 20 seconds. The authors also cited the work of a prior preliminary study conducted by the FAA wherein a far larger proportion of women (68 percent) could not maintain a slightly larger force of 25 pounds (112.5 N) for 20 seconds. The data pertaining to the foot-operated rudder control yielded the highest success rate. When tested at the FAA limit of 150 pounds (675.0 N) for 30 seconds, only 21 percent of the women failed.

More recently, McDaniel (1981) conducted a study on individuals who met the stature and weight criteria for US Air Force pilots. He reported that substantial numbers of both males and females tested could not effect 4-second maximal right-hand exertions on a stick (cyclic-like) control and on pedal controls that met or exceeded maximum design criteria values cited in MIL-F-8785B (Department of Defense 1974). Fifty percent of the males could not exert a criterion-level "stick right" exertion of 35 pounds (157.5 N) and none of the females could generate the exertion required. Additionally, 95 percent of the females and 5 percent of the males failed to

produce a maximum-level 35-pound (157.5 N) "stick left" exertion. Whereas all males could attain the required level of force for forward and aft stick exertions, substantial percentages of women could not attain the 35 pound (157.5 N) level in the forward (28 percent) and aft (40 percent) directions. Failures to meet leg exertion requirements were substantially less for both groups. Failure rates encountered on the left pedal were 7 percent among males and 11 percent among females. For the right pedal, even fewer failures occurred: 0 percent among males, 5 percent among females.

METHOD

SUBJECTS

One hundred forty subjects, 74 males and 66 females, participated in the study. These subjects comprised eight groups divided by preselected ranges of stature (Table 1). Six groups represented males and females of comparable stature in the following three ranges: 159-163 cm; 164-167 cm; and 174-177 cm. With the exception of a cell size of 10 in the group of tallest women, the number of subjects in each group ranged from 16-20. The emphasis was upon the assessment of strength capabilities of personnel just above and just below the stature (162.7 cm, 64 in) which, prior to 1980, had been the traditional lower limit for entrance into the US Army aviator flight training program.

Two additional groups for which comparably-sized individuals of both sexes were not available were also included in the study: females less than 159 cm (62.5 inches) and males greater than 183 cm (72.0 inches).

TABLE 1

STATURE AND GENDER-APPROPRIATE, PERCENTILE EQUIVALENTS FOR GROUPS OF MALE AND FEMALE SUBJECTS.

GENDER	STATURE (cm)	PERCENTILE EQUIVALENT	NUMBER OF SUBJECTS
Female	$\leq$158.9	<28	18
Male	159.0-162.9	2-5	20
Female	159.0-162.9	29-52	19
Male	163.0-166.9	5-12	19
Female	163.0-166.9	52-73	19
Male	174.0-176.9	49-67	19
Female	174.0-176.9	94-98	10
Male	$\geq$183.0	>93	16

PROCEDURE

Subjects, in pairs, came to the laboratory for the entire day. Following an initial briefing regarding the purpose of the study and description of the tasks to be performed, they were assigned randomly to initially perform either a series of maximal voluntary isometric single-control exertions on helicopter controls or a series of simultaneous multiple control exertions (not reported here). During both series, subjects also performed several additional reference exertions (e.g., hand grip) and dynamic force-loaded arm and leg tracking tasks. Subsequent to the completion of whichever series was assigned first, the other series was completed following a 90-minute lunch break. Those exertions reported here address the 10 single-control, center-position exertions performed by each subject.

Each exertion consisted of a 4-second maximal voluntary exertion in a specified direction upon a specified control. Interexertion intervals (IEIs) of 2 minutes were employed. The timing of the exertions, the designation of the helicopter control to be used, and the direction-of-exertion to be applied all were accomplished by using a programmed electronic timer in conjunction with a slide projector and a color-coded series of lights. Seven seconds prior to the required onset of the exertion, the slide projector displayed a 1 m by 1 m image of the helicopter controls upon a screen located directly in front of the subject approximately 2.5 m away. Depicted on it (Figure 1) were all four controls: cyclic, collective, left and right pedals. Each was shown in the same location on each trial. The controls which were not to be used during a given trial were masked by a crosshatch of lines at 45 degrees to the horizontal, leaving only the control-of-interest clearly depicted and emphasized. Immediately adjacent to the designated control, an arrow was shown to indicate the direction in which the exertion was to be performed.

The operation of the projector, the timing of the lights, and the on-off recording cycle of a 14-channel tape recorder were achieved through the use of electronic timing and control apparatus in conjunction with an interval tape timer. The tape recorder started running 4 seconds before the subjects were cued to begin their exertions and remained on for 4 seconds after the completion of the exertion.

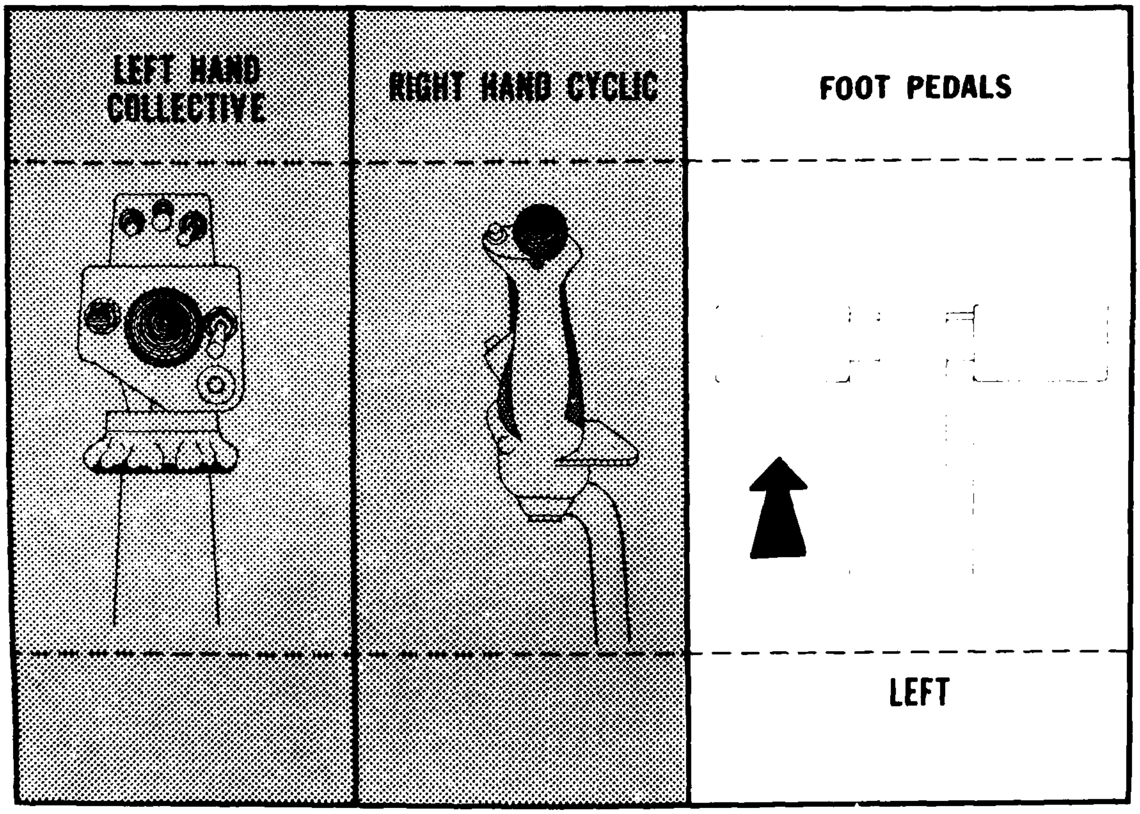

FIGURE 1. Sample Exertion-Identifying Instructional Display.

The timing of the exertion was controlled through the use of a series of color-coded lights located slightly to the right of the forward field-of-view, approximately 1.5 m from the subject. Five seconds prior to the onset of the exertion, an amber lamp was lit. The subjects were informed that this meant they should position their hands or feet on the proper controls at this time in preparation for the required exertion. Two seconds prior to the time the exertion was to begin, the amber lamp was extinguished and a green lamp was lighted. It remained on for the succeeding 8 seconds. The subjects were instructed that when the green lamp was illuminated they were to initiate the exertion in a prompt, linear fashion such that it was at a maximum within 2 seconds of the

onset of the green lamp. Two seconds after the onset of the green lamp, a red lamp was lit and remained on for the next 4 seconds. During this time the subject was instructed to hold his exertion at the maximum level. When the red lamp was extinguished, the subject was to relax his exertion. Two seconds later the green lamp was extinguished and the subject released the control.

The entire series of 20 single-control exertions involved eight upon the cyclic, six upon the collective, and three upon each pedal. All subjects performed cyclic exertions in all four directions (0, 90, 180, and 270 degrees) with the cyclic at its center position. Exertions in both up and down directions were performed on the collective at three positions: center, maximum up, and maximum down. Exertions on each pedal were performed at the center forward and aft positions. In addition to these 16 exertions, approximately one-fourth of the subjects in each group, randomly designated, performed exertions in all four directions upon the cyclic located at one of its extreme positions (maximum forward, aft, left, or right). Only the data pertaining to the 10 center-position exertions are addressed in this report.

The sequencing of the exertions was designed to permit at least a 4-minute rest between exertions on the same control (e.g., exertions on the cyclic) and at least 10 minutes rest between repetitions of the same directional exertion on a control (e.g., exertions to the left on the cyclic). On a random basis, one of the two subjects appearing for each session performed the fixed sequence in one direction; the other performed it in the reverse direction.

No feedback was provided the subjects regarding their efforts. An occasional polite restatement of their task (to perform maximal exertions) routinely was rendered approximately midway through the series; however, there was no effort to continuously exhort maximal performance from the subjects.

In consonance with the variation in the selection of actual in-the-aircraft seat adjustments noted among experienced aviators during another portion of this research program, subjects selected their own seat position with regards to the controls with the controls positioned at the centers of their respective ranges of movement. The lap belt was fastened snugly. The shoulder harness was in place, but unlocked to allow freedom of forward bending movement. The unlocked harness is consistent with current aircrew instruction.

All controls were instrumented with strain gages. Output voltages were recorded on a 14-channel FM tape recorder. The strain gages were calibrated before each pair of subjects was

run. This was accomplished by hanging lead weights of known value to a steel cable and pulley assembly which was attached to the control to be calibrated. The calibration sequence was 0 N, 135 N (30 lbs.), 270 N (60 lbs.), and 405 N (90 lbs.). A 30-second recording of the output of the strain gages was made for each of these weights. The cyclic was calibrated in both the fore-aft and the left-right directions, and the collective was calibrated for both up-down and left-right forces. Each pedal was calibrated individually in the forward direction only. In addition to force-related analog voltages, the tapes contained subject/group identification voltage codes and voice-input session identification information.

For each exertion, analog data from the data tapes were sampled at 10 Hz and digitized. From the 40 data points resulting from the 4-second maximal exertion period for each exertion, peak values were determined and mean values were computed.

RESULTS

Available guidelines which cite maximum limits for control forces are employed as the context against which the present force data were evaluated. As of the date of this report, there exists only one published standard, MIL-H-8501A (Department of Defense 1961). Two subsequent attempts have been made to update this standard. The first was in 1973 when a draft of a proposed revision to MIL-H-8501A was circulated for comment; however, the proposed revision was not fielded. Currently, there is another effort to update this standard. Referred to here as MIL-H-8501X, control force limits which were being considered in the early 1980s for inclusion in this document are depicted in Table 2 along with corresponding information from the 1961 version and the unpublished 1973 revision.

It is noted that the two most recent attempted updates refer to various "levels" of force. These reflect a recognition that variation in forces required to control the aircraft will occur when the aircraft is ". . . required to operate under abnormal conditions" (MIL-F-83300, page 10, Department of Defense 1970). These abnormal conditions result from flying the aircraft outside the normal "Operational Flight Envelope" or controlling the aircraft subsequent to a hydraulics failure or malfunction.

The forces apropos to Level 1 are those which apply to normal aircraft flight operation. Level 2 is defined in MIL-F-83300 as being values which reflect a degradation in flying qualities which is acceptable only for nonfailure-related flight outside the Operational Flight Envelope, but within the allowable "Within Service Flight Envelope." In addition to the Within Service Flight Envelope application, Level 2 also is applicable to failure-related flying quality degradation for such failures as are likely to occur less than once every 100 flights. Forces associated with Level 3 are the limits of forces which should occur during the type of failures which occur less than once every 1000 flights. The values cited in Table 2 show that higher levels of force are deemed acceptable for increasingly rare aircraft failures or malfunctions.

TABLE 2

CONTROL FORCE DESIGN CRITERIA

Reference	Cyclic Fore-aft	Cyclic Left-Right	Collective	Pedals	Simultaneous*	Duration (Sec)
MIL-H-8501A (1961)	112.5 N (25 lb)	67.5 N (15 lb)	112.5 N (25 lb)	360.0 N (80 lb)	NS	NS
MIL-H-8501** (1973)						
Level 1	45.0 N (10 lb)	31.5 N (7 lb)	31.5 N (7 lb)	135.0 N (30 lb)	Yes	NS
Level 2	90.0 N (20 lb)	67.5 N (15 lb)	67.5 N (15 lb)	225.0 N (50 lb)	Yes	NS
MIL-H-8501X*** (19XX)						
Level 1	45.0 N (10 lb)	22.5 N (5 lb)	45.0 N (10 lb)	112.5 N (25 lb)	NS	5
Level 2	90.0 N (20 lb)	45.0 N (10 lb)	90.0 N (20 lb)	225.0 N (50 lb)	NS	5
Level 3	135.0 N (30 lb)	67.5 N (15 lb)	135.0 N (30 lb)	337.5 N (75 lb)	NS	5

* Refers to a stated requirement to maintain force levels "in combination"; i.e., simultaneously. NS denotes that there was no mention of this aspect of the issue; i.e., it was not stated.

** This proposed change was never published.

*** Values extracted from an early draft of this document; the document is still in preparation.

Tables 3 through 6 provide the results of the comparisons between the single control, center position force exertion data and the various existing and previously considered or proposed maximum control force referents cited in Table 2. Tables 3 and 4 address fore-aft and left-right cyclic exertions, respectively. Table 5 addresses collective exertions, and Table 6 addresses pedal exertions. Each table depicts the percentage of subjects in

each stature/gender-defined group whose 4-second exertions failed to achieve the various referent values cited. Percentage failures are provided for both mean and peak exertion parameters. Descriptive statistics for each of these exertions are provided for all subject groups in Appendix A, Tables A-1 through A-4.

The comparison of the fore-aft exertion data with the various possible maximum control force design limit for fore-aft cyclic exertions (Table 3) revealed relatively few failures. All were encountered among the data pertaining to 4-second exertions in the forward direction. The greatest number occurred among the smallest group of females at the two highest referent values. An unusually low value also was observed for the exertion by one male in the 174-177 cm group. No failures were observed among any of the groups for peak exertions in either direction.

The comparative data for lateral cyclic exertions, Table 4, reflect the occurrence of failures among both the data for 4-second means and the data for recorded peaks. However, these are confined to the two highest referent values (67.5 N and 45.0 N) among individuals in the three smallest groups. Failures observed occurred principally among females during exertions to the right (abductions). The largest percentage of failures (22.2 percent) was found among the abductions performed by the shortest groups of females.

The data pertaining to the left-hand-executed collective exertions appear in Table 5. Note that within this table only the four uppermost referent values were included; the 31.5 N and 45.0 N referents cited in Table 2 have been omitted (for consistency of format among the tables). However, no data-of-interest were deleted since no failures occurred at either of these levels. Among all controls, the failure rates were highest for the collective control. However, such failures were encountered solely among downward exertions. Only one failure was observed among males, that being by an individual in the 163-167 cm group. Failures among females occurred in all stature-determined groups and ranged from 10.5 percent to a high of 42.1 percent for the 4-second mean parameter. Failures also were noted among the recorded peak exertions.

Percentages of failures to attain the four highest levels of possible MIL-STD-8501 control force design limits for pedal controls are cited in Table 6. (For the same reason as cited in the collective-related findings, the lowest level, 112.5 N, was not addressed in the table; no failures were encountered at this level.) Failures pertaining to this area existed only among those in the three smallest groups and were more predominant in the data for left-pedal exertions.

TABLE 3

PERCENTAGES OF SUBJECTS FAILING TO ATTAIN VARIOUS REFERENT LEVELS OF LONGITUDINAL CONTROL FORCE INPUTS DURING 4-SECOND FORE(F)-AFT(A) EXERTIONS ON A CENTER-POSITION CYCLIC AS A FUNCTION OF SUBJECTS' STATURE AND GENDER.

Stature Gender	Exertion Parameter Referent Levels (N)								Peak during 4-second exertion Referent levels (N)							
	135.0		112.5		90.0		45.0		135.0		112.5		90.0		45.0	
	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A
159 cm or less																
Females (N=18)	11.1	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
159-163 cm																
Males (N=20)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=19)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
163-167 cm																
Males (N=19)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=19)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
174-177 cm																
Males (N=19)	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=10)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
183 cm or more																
Males (N=16)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 4

PERCENTAGES OF SUBJECTS FAILING TO ATTAIN VARIOUS REFERENT LEVELS OF LATERAL CONTROL FORCE INPUTS DURING 4-SECOND LEFT(L)-RIGHT(R) EXERTIONS ON A CENTER-POSITION CYCLIC AS A FUNCTION OF SUBJECTS' STATURE AND GENDER.

Stature Gender	Mean of 4-second exertion Referent Levels (N)								Peak during 4-second exertion Referent Levels (N)							
	67.5		45.0		31.5		22.5		67.5		45.0		31.5		22.5	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
159 cm or less																
Females (N=18)	0.0	22.2	0.0	5.6	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0
159-163 cm																
Males (N=20)	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=19)	5.3	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
163-167 cm																
Males (N=19)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=19)	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0
174-177 cm																
Males (N=19)	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=10)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
183 cm or more																
Males (N=16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 5

PERCENTAGES OF SUBJECTS FAILING TO ATTAIN VARIOUS REFERENT LEVELS OF CONTROL FORCE INPUTS DURING 4-SECOND UP(U) AND DOWN(D) EXERTIONS ON A CENTER-POSITION COLLECTIVE AS A FUNCTION OF SUBJECTS' STATURE AND GENDER.

Stature Gender	Mean of 4-second exertion Referent levels (N)								Peak during 4-second exertion Referent levels (N)							
	135.0		112.5		90.0		67.5		135.0		112.5		90.0		67.5	
	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D
159 cm or less																
Females (N=18)	0.0	27.8	0.0	22.2	0.0	11.1	0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0
159-163 cm																
Males (N=20)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=19)	0.0	10.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
163-167 cm																
Males (N=19)	0.0	5.3	0.0	5.3	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=19)	0.0	42.1	0.0	15.8	0.0	5.3	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0
174-177 cm																
Males (N=19)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=10)	0.0	20.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
183 cm or more																
Males (N=16)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 6

PERCENTAGES OF SUBJECTS FAILING TO ATTAIN VARIOUS REFERENT LEVELS OF CONTROL FORCE INPUTS DURING 4-SECOND LEFT(L) OR RIGHT(R) PEDAL EXERTIONS ON CENTER-POSITION PEDALS AS A FUNCTION OF SUBJECTS' STATURE AND GENDER.

Stature / Gender	Mean of 4-second exertion, Referent levels (N)								Peak during 4-second exertion, Referent levels (N)							
	360.0		337.5		225.0		135.0		360.0		337.5		225.0		135.0	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
159 cm or less																
Females (N=18)	11.1	5.6	0.0	5.3	0.0	0.0	0.0	0.0	5.6	5.6	0.0	0.0	0.0	0.0	0.0	0.0
159-163 cm																
Males (N=20)	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=19)	5.3	5.3	5.3	5.3	0.0	0.0	0.0	0.0	0.0	5.3	5.3	0.0	0.0	0.0	0.0	0.0
163-167 cm																
Males (N=19)	0.0	5.3	0.0	5.3	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=19)	10.5	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0
174-177 cm																
Males (N=19)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Females (N=10)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
183 cm or more																
Males (N=16)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The previous tables provide failure-rate data pertaining to participants throughout the range of stature evaluated in the study. However, the focus of the present research effort is to examine the need for invoking minimum strength criteria. Because size is positively correlated with strength (McCormick 1976), the majority of the subjects used in the study were those whose stature corresponded to values close to those which had served or presently serve as minimum anthropometric criteria for entering the Army's flight training program. Prior to 1980, the minimum requirement was 64 inches (162.6 cm), as cited in AR 40-501 (Department of the Army 1960). Subsequent to the issuance of a policy letter to all Army flight surgeons (US Army Aeromedical Center 1980), stature, per se, was provisionally replaced as a minimum criteria by measures of upper- and lower-body reach-related dimensions. These values corresponded roughly to individuals with a stature of 62.5 inches (159 cm).

To be consistent with these previously-employed criteria and to maximize the relevance of the present study to the problem being addressed, the present study included groups of males and females whose stature was just above the traditional 64-inch criterion (those in the 163-167 cm groups), groups whose stature was just below the traditional criterion (those in the 159-163 cm groups), and a group of females whose stature (<159 cm) was below the 62.5 inch stature which corresponded approximately to the stature of personnel meeting the policy-letter-installed reach-related criteria. It was not possible to generate a group of males of stature ≤159 cm, for this stature corresponds to approximately the 1.4th percentile male (McConville *et al*. 1977).

In consonance with previously reported relationships between size and strength (McCormick 1976), most failures occurred in the present study among subjects 167 cm or less. Their data have been separated from those of larger subjects and examined more closely. When subjected to a repeated measures analysis of variance (ANOVA), the results indicated that there were no statistically significant differences between the 159-163 cm and the 163-167 cm groups which were attributable to stature (cyclic: $p>.47$; collective: $p>.28$; pedals: $p>.50$). Gender-related differences, however, were very highly significant (cyclic: $F(1,64) = 37.37$, $p = .0000$; collective: ($F(1,64) = 47.44$, $p = .0000$; pedals: ($F(1,64) = 17.98$, $p = .0001$).

In view of the lack of a statistically significant effect for stature, the data for same-sex subjects 159-167 cm were combined to permit a more reliable approximation of the actual frequency distribution of the data for these subjects (Table 7). The percentiles cited are those which correspond to the percentile equivalent of the various referent limits from their projection onto a smooth curve drawn through the histogram for the force exertion values comprising the lower, relevant portion of the frequency distribution.

TABLE 7

ESTIMATIONS OF PERCENTILE EQUIVALENTS FOR EXISTING AND POSSIBLE REFERENT VALUES FOR MAXIMAL CONTROL FORCE DESIGN LIMITS RELATIVE TO THE DISTRIBUTION OF MEAN VALUES OF 4-SECOND EXERTIONS BY MALES AND FEMALES 159-167 CM IN STATURE.

Controls	Referent Values (N)	Percentile equivalents: Males (N=39) 159-167 cm		Females (N=38) 159-167 cm	
Cyclic					
Direction of exertion:		fore	aft	fore	aft
	135.0	*	*	*	*
	112.5	*	*	*	*
	90.0	*	*	*	*
	45.0	*	*	*	*
Direction of exertion:		left	right	left	right
	67.5	*	2	5	10
	45.0	*	*	*	**
	31.5	*	*	*	*
	22.5	*	*	*	*
Collective					
Direction of exertion:		up	down	up	down
	135.0	*	1	*	28
	112.5	*	1	*	11
	90.0	*	1	*	5
	67.5	*	*	*	*
Pedals		left	right	left	right
	360.0	3	4	9	5
	337.5	***	3	6	*
	225.0	*	*	*	*
	112.5	*	*	*	*

* Denotes no exertion observed smaller than this value.
** One exertion at 45.9
*** One exertion at 338.0

The data from males in Table 7 represents a sample of 39 individuals whose stature corresponds to the 2d-12th percentile among US Army males (McConville et al. 1977). Relative to this sample, it appears that the three lowest cyclic-related values considered for either fore-aft or left-right exertions would pose little difficulty for a similarly constituted sample in the future. As regards the single failure occurring in the right-directed exertions, it is noted that it stems from a value of 53.6 N, a magnitude of exertion which is substantially below the range of values encountered among the four next higher values (73.8-77.0 N). The collective-related data for exertions in the up direction suggest that none of the referent values represent a serious challenge for these males. Although greater difficulties exist regarding the downward exertion, it is the case that the single failure encountered (an exertion of 88.2 N) was considerably smaller than the two next higher exertions (155.7 N and 157.5 N). Were this unusually low value discounted, there would have been no failures whatsoever observed among male collective-related exertions. The left and right pedal data for small males evidenced single failures in each distribution which also were associated with relatively large distances from the two next higher values in each distribution. The lowest value, 338 N, in the left pedal distribution was substantially less than the next two higher values, 419 N and 482 N. Corresponding values for the right pedal distribution were 315 N (lowest) and 399 N and 444 N (next higher two).

With the exception of downward collective-related exertions, the findings for females cited in Table 7 evidence surprisingly little difference from that of males in the overall pattern of failures evidenced. For downward exertions on the collective, however, the percentages of failures encountered were markedly higher than those for males. Moreover, failures for this control/direction combination were evidenced at all but the lowest-level reference value.

Because the study also included a group of females of stature <159 cm, it was possible to achieve an even larger sample (N=56) of women $\leq$167 cm in stature by including their data with those in the 159-167 cm range. By doing so, it is possible to further enhance the reliability of failure-related findings for the group of individuals who would have the greatest difficulty in meeting or exceeding any strength-related criterion.

A second analysis of variance showed no difference between the exertions of female subjects in the smallest group and those in the 159-167 cm range: (cyclic: $p>.53$; collective: $p>.83$; pedals: $p>.82$). Therefore, the exertions for females less than 159 cm were integrated into the data for females 159-167 cm. The resulting comparison of this distribution with the MIL-H-8501-related referents is provided in Table 8.

TABLE 8

ESTIMATIONS OF PERCENTILE EQUIVALENTS FOR EXISTING AND POSSIBLE REFERENT VALUES FOR MAXIMAL CONTROL FORCE DESIGN LIMITS RELATIVE TO THE DISTRIBUTION OF MEAN VALUES OF 4-SECOND EXERTIONS BY ALL FEMALES LESS THAN 167 CM IN STATURE.

Control	Referent Values (N)	Percentile equivalents (N=56)	
Cyclic			
Direction of exertion		fore	aft
	135.0	5	*
	112.5	3	*
	90.0	*	*
	45.0	*	*
Direction of exertion		left	right
	67.5	3	16
	45.0	*	3
	31.5	*	*
	22.5	*	*
Collective			
Direction of exertion		up	down
	135.0	*	28
	112.5	*	14
	90.0	*	7
	67.5	*	*
Pedals		left	right
	360.0	9	5
	337.5	7	5
	225.0	*	*
	112.5	*	*

* Denotes no exertion observed smaller than this value.

The addition of females smaller than 160 cm (Table 8) to those in the 160-167 cm range had the greatest effect on the percentage of failures evidenced per the cyclic-related findings. Whereas there were previously no failures evidenced among fore-aft exertions at any referent level, the inclusion of the smallest

group of females resulted in failures being encountered at both the 135.0 N and 112.5 N levels. Heretofore unencountered failures also were observed at the 45.0 N level for lateral cyclic inputs. The rate-of-failure also was increased to 16 percent from 10 percent at the 67.5 N level. Increases in percentage failures were less substantial for collective- and pedal-related inputs.

The present force exertion failure-rate data for males (N=39) and females (N=56) of stature equal to or less than 167 cm are presented together with each of the existing or subsequently considered upper limits for control forces in Table 9. Since these existing or proposed criteria do not make distinctions between up and down directions of exertion on the collective, or left and right pedals, the values entered into Table 9 for these controls are those which are the most conservative from a hazards-assessment perspective (i.e., the values showing the greatest failure rate).

The "Level 1" values cited in Table 2 for the existing MIL-H-8501A (Department of Defense 1961) include flight conditions which encompass both normal flight and autorotations (paragraphs 3.2.5, 3.2.6, and 3.5.4). At none of the values cited as limits for such flight conditions does there appear to be any reason for concern; no failures were observed. However, it is clear the continued employment of the "Level 2" limits cited in the existing 1961 version (applicable to failure of the hydraulics assist mechanism for the controls) does result in placing some portion of these small males and females "at risk," with females being considerably more at risk than their male counterparts.

Among the values considered as limits during the uncompleted attempt to revise MIL-H-8501A in 1973, it is observed in Table 9 that failures were encountered only among the lateral inputs to the cyclic at Level 2, that corresponding to the extent of degradation in flying quality deemed acceptable under relatively rare occurrences of aircraft malfunction or failure. Percent failures were substantially higher among females (10 percent) than among males (2 percent). There were no failures encountered for any of the values associated with Level 1 criteria.

A comparison of the present force-exertion findings with those values being considered in the most recent effort to revise MIL-H-8501A, i.e., MIL-H-8501X, also revealed no failures at the values proposed for normal flight within the Operational Flight Envelope (Level 1). The limits being considered for Level 2 (i.e., those acceptable during flight outside the Operational Flight Envelope, but within the Service Flight Envelope, or those associated with the type of aircraft malfunction or failure which might be expected to occur in 0.1-<1.0 percent of all flights) would result in failures for only collective-related exertions were they to be adopted. The relatively small percentage of

TABLE 9

ESTIMATED PERCENTILE FAILURES AMONG SMALL MALE AND SMALL FEMALE SINGLE CONTROL EXERTION RELATIVE TO EXISTING AND SUBSEQUENTLY CONSIDERED UPPER LIMITS FOR CONTROL FORCE DESIGN CRITERIA.

Reference	Level	Gender*	Cyclic Fore-Aft	Cyclic Left-Right	Collec-tive	Pedals
MIL-H-8501A**	1		36.0 N	31.5 N	31.5 N	67.5 N
(1961)			(8.0 lb)	(7.0 lb)	(7.0 lb)	(15.0 lb)
		Males	0	0	0	0
		Females	0	0	0	0
	2		112.5 N	67.5 N	112.5 N	360.0 N
			(25 lb)	(15 lb)	(25 lb)	(80 lb)
		Males	0	2	1	4
		Females	3	10	14	9
MIL-H-8501***	1		45.0 N	31.5 N	31.5 N	135.0 N
(1973)			(10 lb)	(7 lb)	(7 lb)	(30 lb)
		Males	0	0	0	0
		Females	0	0	0	0
	2		90.0 N	67.5 N	67.5 N	225.0 N
			(20 lb)	(15 lb)	(15 lb)	(50 lb)
		Males	0	0	0	0
		Females	0	0	0	0
MIL-H-8501X†	1		45.0 N	22.5 N	45.0 N	112.5 N
(19XX)			(10 lb)	(5 lb)	(10 lb)	(25 lb)
		Males	0	0	0	0
		Females	0	0	0	0
	2		90.0 N	45.0 N	90.0 N	225.0 N
			(20 lb)	(10 lb)	(20 lb)	(50 lb)
		Males	0	0	1	0
		Females	0	3	7	0
	3		135.0 N	67.5 N	135.0 N	337.5 N
			(30 lb)	(15 lb)	(30 lb)	(75 lb)
		Males	0	2	[illegible]	3
		Females	5	16	28	7

* Males <167 cm, N=39; Females <167 cm, N=56.

** "Levels," per se, not cited. Level 1 corresponds to the values cited in Table 2, page 2; Level 2 are the values cited in paragraph 3.5.8(a)(2).

*** This proposed change was never published.

† Values extracted from an early draft of this document; the document is still in preparation.

failures likely to be encountered at this level (1 percent males, 5 percent females) were all associated with downward exertions (Tables 7 and 8).

The values being considered for flying quality degradation as would be experienced in aircraft failures occurring in less than one flight per 1000, Level 3, are associated with substantially increased percentages of failures involving all three controls and both sexes. The adoption of these level 3 cyclic-related values would result in failure rates similar to those encountered under the existing 1961 version of MIL-H-8501A. Failures would be manifest in the lateral inputs, especially those in the right direction. The somewhat lower pedal-related value presently being considered for Level 3 (337.5 N) is associated with somewhat smaller failure rates than those associated with the existing criteria (360.0 N). However, the failure rates are relatively small: 3 percent for males, 6 percent for females. By far, the greatest percent failure was that evidenced for collective-related exertions. Confined solely to downward exertions (Tables 7 and 8), the failures observed here occurred primarily among females (28 percent). Failures among males were quite infrequent (1 percent).

If one assumes that the strength of those comprising the present subject samples is not significantly different from corresponding percentile ranges in the entire US Army male and female populations, the percentiles cited in Tables 7-9 represent approximations of the percentage of failures apt to be encountered in future, similarly constituted samples for each of the criteria evaluated independently. It is noted, however, that for referents where failures were encountered, the percentages cited in Tables 7-9 are not those which would apply to the entire population. The percentages which appear there are those which correspond to the portions of their respective male and female populations which would most likely be "at risk"; i.e., the smaller individuals. Tables 7-9 do not reflect the results of the larger males and females tested. Among the males in the two larger groups evaluated, no additional failures were observed for any control or direction. Among the smaller sample of tall women (N=10), additional failures were encountered only in downward exertions on the collective.

Before addressing the issue of cumulative, "set-wise" failure rates, the existing single control/direction failure rates are examined from the perspective of having to identify control force design limits which correspond to specified target levels of failure rates. The information in Table 10 presents an assessment of the estimated force levels (rounded to five Newton increments) which would be likely to result in no failures, 5 percent failures, 10 percent failures, and 20

TABLE 10

ESTIMATIONS OF CONTROL FORCE DESIGN LIMITS REQUIRED TO ACHIEVE MAXIMUM FAILURE RATES OF 20 PERCENT, 10 PERCENT, 5 PERCENT, AND 0 PERCENT AMONG MALES AND FEMALES OF STATURE LESS THAN 167 CM.

Control	Direction of Input	Percent Failure	Design Limits* Males (N=39)	Design Limits* Females (N=56)
Cyclic	Forward	20	195	170
		10	160	155
		5	150	140
		0	135	100
	Aft	20	260	190
		10	240	175
		5	185	160
		0	170	155
	Left	20	125	95
		10	95	85
		5	75	75
		0	65	55
	Right	20	90	70
		10	75	65
		5	70	55
		0	50	40
Collective	Up	20	460	350
		10	355	300
		5	325	250
		0	260	215
	Down	20	190	120
		10	165	105
		5	155	85
		0	85	75
Pedals		20	575	430
		10	485	390
		5	395	325
		0	315	255

* Forces are in Newtons.

percent failures among males and females of stature less than 167 cm for each specified control/direction. An examination of the values in this table permits a gender-related assessment to be made of the impact upon the data base of

selecting a specifically targeted failure rate as being acceptable for these groups of small individuals. In consonance with previous research and the findings previously presented for given failure rates, larger forces are associated with males and females.

The collective-related data in Table 10 clearly illustrate the substantial discrepancy between up and down exertions on the collective. The adoption of a single criterion (e.g., a conservative 200 N) to assure that there were no failures in the upward direction would result in a failure rate of 25 percent among males and 63 percent among females when applied to values associated with downward exertions (as assessed from an examination of the frequency distribution for these exertions).

An adoption of the 85.0 N as a collective-related design force limit corresponding to a 5 percent failure rate among women likely would result in no failures among small males. While such a limit is higher than the 67.5 N value considered in the attempted 1973 revision, it is lower than both the Level 2, 90.0 N value and the Level 3, 135.0 N value considered in the presently, ongoing update effort. The failure rates associated with these two values were 7 and 28 percent, respectively.

The force levels in Table 10 pertained to failure rates likely to be independently encountered for each combination of control and direction. However, the issue of single versus multiple failures by one or more individuals is important in determining the overall impact of adopting any set of multiple, independently assessed criteria. Attempted assessments of "overall" failure rates for the existing 1961 "Level 2" values, and those considered as possible Level 2 and Level 3 values in the presently ongoing efforts to update MIL-H-8501A require additional evaluations of the data to account for the potentially substantial degree of overlap among the failures reported separately for each control limit.*

* Because one or more subjects may fail more than one of the proposed or existing criteria, an estimate of the "overall" failure rate cannot be achieved by simply summing the percent failures occurring at each of the control limits. As an extreme example, if one individual, and only one individual, of 40 failed to achieve all four designated limits for a given level, the actual "overall" failure rate of 2.5 percent, 1 of 40, would be inflated to 10 percent if each failure were counted separately.

Previous research (e.g., McCormick 1976) has shown individuals to have tendencies to be generally strong or weak, as reflected by positive correlations among various measures of strength; i.e., if an exertion by one individual is smaller (or larger) than those of others, then other exertions by the same individual are likely to be similarly smaller (or larger) than those of others. In the present research, this tendency to exhibit greater or lesser force exertions for each of the controls and direction/control combinations also was exhibited (Table 11).

TABLE 11

CORRELATION MATRICES FOR 4-SECOND, SINGLE-CONTROL, CENTER-POSITION EXERTIONS BY MALES AND FEMALES LESS THAN 167 CM IN STATURE.

		Cyclic				Collective		Pedals	
Group		Fore (CF)	Aft (CA)	Left (CL)	Right (CR)	Up (KU)	Down (KD)	Left (PL)	Right (PR)
Males (N=39)	CF	1.00	.77	.63	.67	.75	.81	.74	.65
	CA		1.00	.51	.57	.74	.70	.77	.68
	CL			1.00	.52	.67	.62	.47	.27
	CR				1.00	.73	.70	.57	.51
	KU					1.00	.76	.66	.55
	KD						1.00	.71	.61
	PL							1.00	.81
	PR								1.00
Females (N=56)	CF	1.00	.50	.16	.37	.26	.37	.60	.65
	CA		1.00	.27	.30	.49	.27	.43	.38
	CL			1.00	.66	.23	.43	.15	.23
	CR				1.00	.27	.51	.26	.37
	KU					1.00	.13	.23	.30
	KD						1.00	.41	.48
	PL							1.00	.88
	PR								1.00

Among males, the range of correlations is from +.27, that for the linear relationship between cyclic-left and right pedal exertions, to +.81, that for both the linear relationship between the left and right pedal exertions and between cyclic-forward and collective-down exertions. Most correlations were in the +.50 to +.75 range. Correlations among the exertions by females were generally much smaller, being widely

distributed between [illegible] and +.50. The smallest correlation was that between [illegible] and cyclic-aft exertions (+.16) and the largest [illegible] exertions on the two pedals (+.85).

[illegible] other pairs of exertions exceeded +.50: cyclic-[illegible]-right (+.66), and those between [illegible] exertions on the left (+.60) and right [illegible].

[illegible] multiple failures were more like-[illegible] that overall set-related failures for [illegible] with the values associated with the [illegible] rate observed at any given control/ [illegible] summing across the failure rate [illegible] would significantly over- estimate [illegible] set-[illegible] failure rate.

[illegible] correlations for females indi- [illegible] failure rates are apt to be [illegible] with any of the individual [illegible] were smaller, they were still [illegible] warrant the need for additional [illegible] assess the overall failure rates [illegible] within a set.

[illegible] assessment, the data were reevaluated [illegible] pass-fail criterion; i.e., failure [illegible] a relevant design limit would [illegible] failure." (Conversely stated, [illegible] exertions exceeded their respective [illegible] similar to that which would apply [illegible] Table 12 presents the results of [illegible] with the present data in relation [illegible] sets") of possible Level 3 criteria.

Sets [illegible] correspond, respectively, to the criteria [illegible] version of MIL-H- 8501A, those [illegible] revision, and those in the most recent [illegible].

[illegible] correspond to values chosen from Table [illegible] independently assessed failure rates of [illegible] among females. Because none of the existing [illegible] limits for longitudinal [illegible] used a value [illegible] failure set, set D, was [illegible] the cyclic fore-aft limit [illegible] used in set D) and the [illegible] value in set D).

TABLE 12

ESTIMATION OF OVERALL FAILURE RATES FOR VARIOUS COMBINATIONS OF CONTROL/DIRECTION SPECIFIC DESIGN FORCE LIMITS FOR MALES AND FEMALES LESS THAN 167 CM IN STATURE.

Combination Designation	Upper Limits (Newtons)					Overall Failure Rate (%)	
	Cyclic		Collective				
	Fore-Aft	Left-Right	Up	Down	Pedals	Males	Females
A	112.5	31.5	112.5	112.5	360.0	10.3	26.8
B	90.0	67.5	67.5	67.5	225.0	2.6	5.4
C	135.0	67.5	135.0	135.0	337.5	7.7	37.5
D	140.0	55.0	250.0	85.0	325.0	7.7	14.2
E	155.0	65.0	300.0	105.0	390.0	15.4	33.9
F	170.0	70.0	350.0	120.0	430.0	17.9	53.6
G	135.0	55.0	135.0	85.0	325.0	5.1	10.7
H	135.0	55.0	135.0	105.0	325.0	7.7	14.2
I	135.0	55.0	135.0	120.0	325.0	7.6	21.4

The results appear as set G. Sets H and I differ from set G in that the values (105 N and 120.0 N) corresponding approximately to a 20 percent failure rate among women were employed in place of the 85.0 N value. These values are much closer to the 112.5 N and the 135 N values cited in the present version and that most recently suggested as the Level 3 limit.

The results in Table 12 show that overall set-related failure rates for males ranged from 2.6 percent for the proposed "Level 2" 1973 limits (set B) to 17.9 percent for limits associated with independently-assessed targeted failure rates of 20 percent among females (set F). The corresponding figures for females were substantially higher: 5.4 percent and 53.6 percent. Among the combinations of limits cited, those which would come closest to achieving targeted overall, set-wise failure rates among women of 5 percent, 10 percent, 15 percent, or 20 percent would be those used in sets B, C, D, H, or I respectively. The current, 1961 MIL-H-8501A limits (set A) would result in an overall female failure rate of slightly more than 25 percent. The consideration of other

combinations of values, and the use of values intermediate to those appearing in Table 10 could be employed to achieve other overall set-wise failure rates.

DISCUSSION

The present data are consistent with the substantial already-existing research which shows males to be physically stronger than females of comparable stature (McCormick 1976). They also are consistent with the longitudinal versus lateral differences observed in previous research addressing force inputs to a centered cyclic (or equivalent apparatus) (Laubach et al. 1972; McDaniel 1981).

Relative to the comparison of exertion capabilities with control force design limits, the present results indicate that, in general, there are no difficulties associated with applying any of the existing or proposed Level 1 values to either males or females. However, they do reveal a potential need to revise the existing "Level 2" values of MIL-H-8501A if the proposed limits are to offer maximal assurance that such limits do not exceed the capabilities of all candidates.

It is noted that the "Level 2" values of the present 1961 version of MIL-H-8501A and the Level 2 values of the aborted 1973 update effort are likely to be comparable in their intent to those cited as Level 3 in the presently ongoing effort to update this document since they all refer solely to extents of degradation associated with aircraft malfunction. (Level 2 of the most recent revision effort, in addition to citing a more lenient frequency-of-failure criterion, also indicates that the limits cited are applicable to flight which is outside the normal Operational Functional Envelope, but not involving an aircraft failure.) Reg^rdless of the specific numeric label attached to the various levels, the uppermost control design limits cited in each version entail values which do exceed the capabilities of some of the individuals evaluated in this research undertaking.

Engineering limitations and/or manufacturing costs might make it difficult or impossible to adopt a set of control force design limits (corresponding to Level 3 of the most recent update effort) which would reduce to 1 percent or less the likelihood that one or more of the limits would exceed the capabilities of individuals of the size evaluated in the present study. However, if this is deemed desirable and feasible, an examination of the distribution of exertions recorded in the present research (Tables A-1 through A-4) indicates the following control force design limits would be necessary: cyclic fore-aft, 100 N; cyclic left-right, 40 N; collective, 75 N; pedals 250 N.

The values cited above are those which are consistent in format with the type of control/direction-of-exertion limits which have been employed in all versions (existing and proposed revisions) of MIL-H-8501A. However, it is apparent

from the findings of the present research that the use of differential up-down assists on the collective control would enable considerably higher limits to be allowed for upward exertions. The present data consistently have identified the capabilities of small individuals to be substantially less during the execution of downward-directed pushes on the collective than were their exertions during upward-directed pulls. If direction-specific collective force input limits were to be employed, the present findings indicate that to preclude failure downward limits should remain at 75 N; however, the limit for upward exertions could be increased to 235 N.

From another perspective, it was noted that the subjects participating in the present research were unencumbered by the additional clothing requirements associated with military operations in hostile, cold weather environments. Research previously undertaken by the US Navy (Gregoire 1977) has documented the degradation in range of cockpit-referenced movement resulting from the wear of aircrew clothing. More recently, research conducted (Cote and Schopper 1984) to assess linear anthropometric criteria for Army aircraft while wearing a cold weather, armored vest, chemical defense clothing configuration revealed that such additional bulk adversely affected the reach capabilities of small personnel. If the small subjects in the present study had been required to wear such clothing, their ability to perform downward-directed exertions on the collective likely would have been curtailed to an even greater extent than was evidenced in the present data. (The extent of force degradation on the other controls, if any, likely would be substantially less; the bulk of the clothing and rigidity of the armored vest are envisioned to take their highest toll during exertions which require some degree of forward bending at the waist.) The determination of the actual magnitude of force degradation will require additional research.

The findings and discussion provided here reflect the need for possible consideration of direction-specific design force limits for the collective. The existing standard (and the revisions previously and currently considered) employ a single value applicable to both upward- and downward-directed forces. However, these same documents also employ different limits for longitudinal and lateral cyclic force inputs. There is a need for differential, direction-specific magnitudes of hydraulic assist for the operation of the collective. This has been demonstrated by other research performed in this laboratory. Schopper, Wells, and Kaylor (in preparation) have recorded and analyzed the actual forces applied to the controls of an Army UH-1 utility helicopter during the final 60 seconds prior to touchdown during the execution of "hydraulics-off" approaches and landings. These data clearly

reflected much larger collective force inputs being employed in the downward direction than in the upward direction. Whether or not the design and fabrication of such a system is feasible and/or desirable from engineering and cost-related perspectives is unknown.

The discussion to this point has focused on MIL-H-8501A-related matters. The present data also have considerable relevance to the issue of aviator selection standards. For several reasons, the percentages cited as failure rates in this report are believed to overestimate the likelihood of failures which might be encountered if comparable levels of strength criteria were to be adopted as part of any medical examination/screening program employed to evaluate individuals actually seeking to become (or remain) Army aviators. One factor is the individuals' motivation to perform at a maximal level. In contrast to the lack of any actual concrete, realizable incentive to perform well on the part of participants in the present study, those actively seeking to enter flight school or remain on flying duty would have considerable motivation for performing well. Some previously performed research has shown that enhanced strength performance can result from experimental attempts to manipulate the participants' level of motivation (Johnson and Nelson 1967), although other research investigating this variable has shown no effect (Jones 1962) or mixed results (Voor, Lloyd and Cole 1969).

It also is likely that any series of strength exertions that might be employed in a screening battery would consist of fewer exertions than were required of participants in this study. Although a statistical analysis revealed no significant main effect due to order-of-exertion in the present effort, it is apt to be the case that highly-motivated individuals undergoing selection-related screening tests would be aware of the fact that they would have to perform only a known, small number of exertions. Accordingly, they would be apt to go "all out" during each exertion, thereby attaining larger exertions than those evidenced here. Subjects participating in the present study knew they were involved in an entire day of testing; hence, some unknown degree of self-imposed pacing (restraint) may have been employed. For this reason, too, the values reported here may be smaller than would be evidenced during any actual selection-related strength testing.

Another factor which suggests that the magnitudes of the exertions rendered by the participants in the present study may have been less than the best of which they were capable is they knew each specific exertion was to be performed only once. Recently, Strobbe and Plummer (1984) reported their results of an evaluation of multiple sequential trials. They indicated an average of 2.43 attempts was required by

individuals to achieve their maximal exertion. However, in a pilot study undertaken prior to initiating the present research, four subjects performed a series of 20 maximal voluntary exertions upon a cyclic control. They alternately performed exertions in the fore and aft directions on either even- or odd-numbered trials. Each of these subjects performed the series once with a 2-minute interexertion interval (IEI) and once with a 4-minute IEI. A 1-week recovery period was imposed between the sessions. The IEI employed first was randomly determined such that two employed the 2-minute IEI during the first session and the 4-minute IEI during the second. The order was the reverse for the remaining two subjects. The results were that in spite of significant increases in the degree of subjectively reported effort and fatigue over trials, there was not a statistically significant effect of trials on the magnitudes of the exertions performed.

The present findings have identified the downward-directed collective exertion as that which is associated with the highest failure rates in relation to existing control force design limits. Failure rates among females were markedly higher than those for males. As cited previously, there was no statistically significant difference encountered among the three stature-defined groups of females whose height was 167 cm or less. Too, the correlations between downward-directed collective exertions and female height and female weight (and their weighted combination) were all small ($r = +.02$ to $+.21$) and statistically nonsignificant. The corresponding correlations for males were moderate in magnitude ($r = +.31$ to $+.35$) and statistically significant ($p<.03$). When all males and all females were included in their respective correlational analyses, the magnitudes of the correlations increased, but the same patterns prevailed (females $r = +.14$ to $+.23$, males $= +.40$ to $+.45$).

A final comment is operationally oriented and independent of the strength and design factors previously addressed. One of the principal reasons for investigating the strength-related issue was the possibility that smaller individuals could not perform the simulated emergency "hydraulics-off" approaches and landings required of them during flight training. It is the case, however, that recently there has been distributed a Department of the Army (DA) policy (message, DAMO-FDZ, 15 April 1985, subject: Helicopter Emergency Touchdown Procedures) which prohibits further employment of the "hydraulics-off" approaches and landings during training (except for instructor pilot training) and in-flight flying proficiency ("check ride") evaluations. Hence, the frequency with which an aviator will be exposed to such force levels has been markedly reduced.

CONCLUSIONS

The findings of the present research support the following conclusions:

a. Existing and previously proposed design criteria for the upper limits of force to be applied to helicopter controls during normal operational flight are compatible with the brief, 4-second maximal exertion capabilities of all males and females tested.

b. Existing and proposed design control force limits pertaining to flight outside the normal operational flight envelope do exceed the capabilities of some of the individuals tested. Estimations from the present data suggest that among the portion of the population considered to be most at risk (i.e., small individuals, designated here as those less than 167 cm, 65.7 inches in stature), 10 percent of the males and 27 percent of the females might fail to achieve one or more of the upper limits cited in the existing 1961 version of MIL-H-8501A.

c. Failure rates (in relation to existing or proposed design limits for other than the normal operational flight envelopes) were generally highest for collective-related exertions; however, virtually all of the failures encountered on this control were associated with downward exertions. Continued employment of a single design limit for collective operation is untenable unless it is based upon downward exertions.

d. For a number of reasons, it is believed that were the present MIL-H-8501A control force design limits to be employed as criteria, the present data would overpredict the percentage of strength-related failures likely to be encountered among the self-selected, highly motivated population of individuals seeking entry into the Army flight training program.

e. Future research is needed to determine the degree to which helicopter control force exertions are degraded by the added bulk of a "worst case" tactical clothing configuration.

f. It is emphasized that most of the tables and the discussion provided here pertained to males and females whose stature was less than 167 cm. Therefore, the failure rates discussed apply only to the shortest 12 percent of Army males and the lowermost 75 percent of Army females. Because there did exist moderate correlations between male sizes (heights and/or weights) and the magnitude of their downward-directed collective exertions, it is likely that the failure rates cited for males $\leq$167 cm are substantially higher than those

which exist in the overall Army male population. The degree of overprediction among females is apt to be considerably less because (1) the size-related correlations were much smaller among the data for females $\leq$167 cm, and (2) the data for females corresponds to a considerably larger portion of the population (through the 75th percentile, versus the 12th percentile for males).

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APPENDIX A

DESCRIPTIVE STATISTICS FOR HELICOPTER-CONTROL-REFERENCED EXERTIONS AS A FUNCTION OF SUBJECT STATURE AND GENDER

TABLE A-1

CENTER POSITION CYCLIC FORE-AFT EXERTIONS
AS A FUNCTION OF SUBJECT STATURE AND GENDER
(VALUES ARE IN NEWTONS).

STATURE	GENDER	CYCLIC FORWARD MEAN	CYCLIC AFT MEAN	CYCLIC FORWARD PEAK	CYCLIC AFT PEAK
159 cm or less	FEMALES:				
	No. Subjects	18	18	18	18
	Mean	211.8	266.2	253.2	320.4
	Standard Deviation	51.5	56.9	61.1	63.7
	Minimum Value	100.8	177.8	139.5	214.7
	Maximum Value	278.1	372.6	360.9	461.7
	Median	224.5	261.5	266.0	322.5
159-163 cm	MALES:				
	No. Subjects	20	20	20	20
	Mean	291.5	339.8	358.5	412.6
	Standard Deviation	95.6	71.8	119.4	94.5
	Minimum Value	152.1	172.4	163.4	187.2
	Maximum Value	443.7	470.3	585.5	585.5
	Median	302.5	345.5	384.0	408.5
	FEMALES:				
	No. Subjects	19	19	19	19
	Mean	221.8	262.1	272.3	319.9
	Standard Deviation	45.7	78.5	51.1	87.1
	Minimum Value	147.2	155.7	175.1	180.0
	Maximum Value	285.3	482.9	364.1	500.0
	Median	223.0	245.0	278.0	300.0
163-167 cm	MALES:				
	No. Subjects	19	19	19	19
	Mean	330.0	361.9	412.6	436.7
	Standard Deviation	122.4	102.7	149.5	122.6
	Minimum Value	136.4	188.6	196.2	230.4
	Maximum Value	575.1	473.0	675.5	596.3
	Median	324.0	398.0	396.0	479.0
	FEMALES:				
	No. Subjects	19	19	19	19
	Mean	240.0	262.0	293.6	316.7
	Standard Deviation	75.6	64.3	86.8	86.0
	Minimum Value	144.0	158.0	170.6	183.6
	Maximum Value	446.4	377.6	516.6	482.4
	Median	223.0	274.0	276.0	314.0

TABLE A-1 (Cont)

CENTER POSITION CYCLIC FORE-AFT EXERTIONS
AS A FUNCTION OF SUBJECT STATURE AND GENDER
(VALUES ARE IN NEWTONS).

STATURE	GENDER	CYCLIC FORWARD MEAN	CYCLIC AFT MEAN	CYCLIC FORWARD PEAK	CYCLIC AFT PEAK
174-177 cm	MALES:				
	No. Subjects	19	19	19	19
	Mean	334.1	349.5	428.5	431.7
	Standard Deviation	93.5	97.1	76.9	104.0
	Minimum Value	158.4	125.1	243.9	200.7
	Maximum Value	464.0	502.7	536.4	596.7
	Median	344.0	361.0	443.0	446.0
	FEMALES:				
	No. Subjects	10	10	10	10
	Mean	234.8	304.3	280.0	356.9
	Standard Deviation	73.0	86.3	79.3	102.4
	Minimum Value	138.6	180.5	166.1	203.4
	Maximum Value	315.0	485.6	379.8	546.8
	Median	245.5	284.0	289.0	324.0
183 cm or more	MALES:				
	No. Subjects	16	16	16	16
	Mean	379.6	389.7	475.3	485.7
	Standard Deviation	133.1	136.1	140.0	141.8
	Minimum Value	197.6	166.1	257.4	214.7
	Maximum Value	685.4	760.1	685.4	760.1
	Median	375.0	386.0	461.0	510.5

TABLE A-2

CENTER POSITION CYCLIC LEFT-RIGHT EXERTIONS
AS A FUNCTION OF SUBJECT STATURE AND GENDER
(VALUES ARE IN NEWTONS)

STATURE	GENDER	CYCLIC LEFT MEAN	CYCLIC RIGHT MEAN	CYCLIC LEFT PEAK	CYCLIC RIGHT PEAK
159 cm or less	FEMALES:				
	No. Subjects	18	18	18	18
	Mean	135.1	93.9	152.4	115.9
	Standard Deviation	48.2	33.3	26.8	37.1
	Minimum Value	86.9	40.5	108.0	63.0
	Maximum Value	296.6	177.8	206.6	192.2
	Median	129.5	90.0	150.0	105.0
159-163 cm	MALES:				
	No. Subjects	20	20	20	20
	Mean	175.4	116.4	216.6	146.3
	Standard Deviation	53.2	39.9	65.3	43.3
	Minimum Value	77.9	53.6	84.2	90.0
	Maximum Value	281.7	235.8	334.4	288.5
	Median	171.0	106.5	214.0	143.5
	FEMALES:				
	No. Subjects	19	19	19	19
	Mean	122.2	94.4	147.2	114.5
	Standard Deviation	29.2	23.9	32.6	28.6
	Minimum Value	58.1	62.1	89.6	83.7
	Maximum Value	179.1	149.9	226.8	188.6
	Median	122.0	87.0	139.0	107.0
163-167 cm	MALES:				
	No. Subjects	19	19	19	19
	Mean	188.3	133.1	299.2	162.3
	Standard Deviation	73.3	40.9	82.1	48.3
	Minimum Value	68.4	73.8	108.5	99.9
	Maximum Value	376.2	203.9	447.8	273.2
	Median	193.0	118.0	229.0	136.0
	FEMALES:				
	No. Subjects	19	19	19	19
	Mean	112.3	96.3	135.4	106.6
	Standard Deviation	25.0	24.1	31.4	31.4
	Minimum Value	72.0	45.9	90.5	59.0
	Maximum Value	154.8	153.9	182.7	194.4
	Median	114.0	83.0	129.0	100.0

TABLE A-2 (Cont)

CENTER POSITION CYCLIC LEFT-RIGHT EXERTIONS
AS A FUNCTION OF SUBJECT STATURE AND GENDER
(VALUES ARE IN NEWTONS).

STATURE	GENDER	CYCLIC LEFT MEAN	CYCLIC RIGHT MEAN	CYCLIC LEFT PEAK	CYCLIC RIGHT PEAK
174-177 cm	MALES:				
	No. Subjects	19	19	19	19
	Mean	206.7	149.4	257.0	189.6
	Standard Deviation	39.1	31.7	44.3	47.5
	Minimum Value	159.8	98.1	203.9	116.6
	Maximum Value	302.9	207.9	335.3	305.1
	Median	192.0	148.0	238.0	188.0
	FEMALES:				
	No. Subjects	10	10	10	10
	Mean	137.3	97.2	167.2	116.1
	Standard Deviation	37.1	18.5	49.2	22.8
	Minimum Value	93.2	68.0	113.0	84.6
	Maximum Value	221.4	123.8	274.5	145.8
	Median	130.5	96.5	153.5	114.0
183 cm or more	MALES:				
	No. Subjects	16	16	16	16
	Mean	244.6	174.8	309.7	214.1
	Standard Deviation	68.4	61.3	74.2	80.3
	Minimum Value	136.4	87.8	169.7	102.6
	Maximum Value	359.1	292.5	441.5	403.7
	Median	222.5	157.5	304.0	195.5

TABLE A-3

CENTER POSITION COLLECTIVE EXERTIONS AS A FUNCTION OF SUBJECT STATURE AND GENDER (VALUES ARE IN NEWTONS).

STATURE	GENDER	COLLECTIVE UP MEAN	COLLECTIVE DOWN MEAN	COLLECTIVE UP PEAK	COLLECTIVE DOWN PEAK
159 cm or less	FEMALES:				
	No. Subjects	18	18	18	18
	Mean	410.5	198.1	477.3	256.8
	Standard Deviation	93.6	90.7	101.0	102.4
	Minimum Value	237.2	76.1	350.6	120.2
	Maximum Value	604.4	396.5	720.5	458.1
	Median	389.0	189.0	463.5	237.5
159-163 cm	MALES:				
	No. Subjects	20	20	20	20
	Mean	548.0	288.9	658.2	383.0
	Standard Deviation	132.8	125.6	156.3	158.9
	Minimum Value	260.1	155.7	282.2	168.7
	Maximum Value	794.7	563.9	929.7	738.5
	Median	547.0	245.0	666.0	340.0
	FEMALES:				
	No. Subjects	19	19	19	19
	Mean	404.3	209.6	489.5	262.0
	Standard Deviation	63.9	71.6	70.4	85.0
	Minimum Value	299.7	102.2	368.1	149.1
	Maximum Value	535.5	323.5	595.4	418.1
	Median	428.0	200.0	489.0	240.0
163-167 cm	MALES:				
	No. Subjects	19	19	19	19
	Mean	589.6	372.2	699.8	468.7
	Standard Deviation	166.3	164.6	200.6	209.7
	Minimum Value	325.4	88.2	345.6	146.3
	Maximum Value	977.9	738.5	1237.5	949.1
	Median	573.0	354.0	691.0	430.0
	FEMALES:				
	No. Subjects	19	19	19	19
	Mean	409.0	174.9	488.4	236.1
	Standard Deviation	92.1	91.3	101.6	119.5
	Minimum Value	219.6	85.5	252.5	132.3
	Maximum Value	561.2	424.8	638.1	577.4
	Median	396.0	151.0	475.0	189.0

TABLE A-3 (Cont)

CENTER POSITION COLLECTIVE EXERTIONS AS A FUNCTION OF SUBJECT STATURE AND GENDER (VALUES ARE IN NEWTONS).

STATURE	GENDER	COLLECTIVE UP MEAN	COLLECTIVE DOWN MEAN	COLLECTIVE UP PEAK	COLLECTIVE DOWN PEAK
174-177 cm	MALES:				
	No. Subjects	19	19	19	19
	Mean	551.3	500.1	713.6	639.6
	Standard Deviation	182.9	133.1	146.4	147.8
	Minimum Value	153.0	279.0	470.3	378.5
	Maximum Value	936.0	738.9	1062.9	926.1
	Median	555.0	475.0	688.0	638.0
	FEMALES:				
	No. Subjects	10	10	10	10
	Mean	445.5	252.1	506.9	318.4
	Standard Deviation	79.2	104.9	83.3	111.2
	Minimum Value	275.4	77.9	356.9	81.0
	Maximum Value	545.9	394.2	642.2	466.2
	Median	451.5	254.0	496.0	332.5
183 cm	MALES:				
or more	No. Subjects	16	16	16	16
	Mean	556.0	483.1	698.2	629.3
	Standard Deviation	160.8	134.4	168.1	186.7
	Minimum Value	212.4	290.3	392.0	358.7
	Maximum Value	831.2	749.3	991.8	896.0
	Median	593.0	464.0	701.5	592.0

TABLE A-4

CENTER POSITION PEDAL EXERTIONS AS A FUNCTION
OF SUBJECT STATURE AND GENDER
(VALUES ARE IN NEWTONS)

STATURE	GENDER	LEFT PEDAL MEAN	RIGHT PEDAL MEAN	LEFT PEDAL PEAK	RIGHT PEDAL PEAK
159 cm or less	FEMALES:				
	No. Subjects	18	18	18	18
	Mean	516.7	535.6	604.5	638.0
	Standard Deviation	148.3	177.7	186.5	218.4
	Minimum Value	264.2	256.1	284.9	268.2
	Maximum Value	869.9	989.1	980.6	1080.5
	Median	478.5	506.5	574.5	595.5
159-163 cm	MALES:				
	No. Subjects	20	20	20	20
	Mean	762.9	825.0	893.8	959.8
	Standard Deviation	202.0	251.7	250.1	320.0
	Minimum Value	338.0	399.2	370.4	436.5
	Maximum Value	1098.0	1266.8	1283.9	1574.6
	Median	716.0	757.5	897.5	889.5
	FEMALES:				
	No. Subjects	19	19	19	19
	Mean	584.4	629.6	696.1	728.0
	Standard Deviation	177.0	218.3	210.2	248.1
	Minimum Value	300.2	294.8	370.4	329.9
	Maximum Value	1000.8	1188.9	1179.9	1387.4
	Median	575.0	589.0	665.0	682.0
163-167 cm	MALES:				
	No. Subjects	19	19	19	19
	Mean	810.0	854.1	964.7	1015.0
	Standard Deviation	280.9	345.0	335.0	390.9
	Minimum Value	419.4	315.5	495.5	339.3
	Maximum Value	1434.2	1652.9	1525.1	1782.0
	Median	722.0	803.0	902.0	999.0
	FEMALES:				
	No. Subjects	19	19	19	19
	Mean	599.7	642.3	707.0	740.7
	Standard Deviation	170.8	238.6	206.7	289.4
	Minimum Value	327.6	414.0	363.6	440.6
	Maximum Value	900.0	1227.2	1125.9	1397.7
	Median	553.0	537.0	677.0	628.0

TABLE A-4 (Cont)

CENTER POSITION PEDAL EXERTIONS AS A FUNCTION
OF SUBJECT STATURE AND GENDER
(VALUES ARE IN NEWTONS).

STATURE	GENDER	LEFT PEDAL MEAN	RIGHT PEDAL MEAN	LEFT PEDAL PEAK	RIGHT PEDAL PEAK
174-177 cm	MALES				
	No. Subjects	19	19	19	19
	Mean	948.2	1110.1	1179.4	1357.8
	Standard Deviation	295.0	320.3	302.1	327.2
	Minimum Value	601.2	603.0	735.3	732.6
	Maximum Value	1606.5	1715.4	1801.4	1941.8
	Median	887.0	1020.0	1141.0	1327.0
	FEMALES:				
	No. Subjects	10	10	10	10
	Mean	771.9	738.4	911.2	936.0
	Standard Deviation	212.3	184.2	217.6	276.3
	Minimum Value	423.9	467.1	529.7	608.0
	Maximum Value	1241.6	957.2	1305.5	1507.1
	Median	751.0	736.5	942.5	883.0
183 cm or more	MALES:				
	No. Subjects	16	16	16	16
	Mean	1220.2	1268.7	1441.4	1517.1
	Standard Deviation	372.2	395.7	363.4	403.2
	Minimum Value	626.9	618.8	740.3	745.7
	Maximum Value	1921.1	1889.6	2080.8	2186.6
	Median	1212.5	1213.5	1480.5	1375.5

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